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An Economic Analysis of Agricultural Practices Related to Water Quality

The Ontario (Oregon) Hydrologic Unit Area

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Abstract

This paper evaluates the effects of adopting Best Management Practices (BMPs) on groundwater quality in the Ontario (Oregon) HUA by incorporating time lags associated with nitrate leaching and groundwater flow. Results indicate that the Federal drinking water standard of no more than 10 ppm may be accomplished in 12 years by adopting improved irrigation systems such as auto-cutback systems or solid-set sprinkler systems. However, the adoption of both improved irrigation systems and nutrient management systems, such as sidedressing and ceasing fall fertilization, would be necessary to meet the strict Oregon drinking water standard of 7 ppm.

Keywords: groundwater quality, BMPs, hydrology, Ontario HUA.

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C. S. Kim, Ronald Fleming, Richard Adams, Marshall English, and C. Sandretto[1]

Introduction

The United States Department of Agriculture (USDA) Water Quality Initiative is being implemented during FY 1990-94 in response to increased public concern about agriculture's contribution to the nonpoint source pollution problem. The USDA initiative defines an effort to protect the Nation's ground and surface water from potential contamination by agricultural chemicals and wastes, especially pesticides and nutrients. The USDA Water Quality Program Plan integrates the expertise of USDA agencies to promote the use of environmentally and economically sound farm production practices. The plan provides educational, financial, and technical assistance to farmers for implementing measures to enhance water quality by reducing or preventing contamination of ground or surface water from agricultural nonpoint sources.

The USDA 5-year action plan includes the selection of Hydrologic Unit Areas (HUA) from agricultural watersheds or aquifer-recharge areas where impairment by agricultural nonpoint sources is significant. These HUA projects involve conservation planning and treatment as a joint effort by Federal, State, and local agencies. USDA cooperating agencies will provide assistance to producers in meeting State water quality goals without undue economic hardship. Information gathered from each HUA project will provide a basis for expanding application to other areas with similar groundwater quality problems (Soil Conservation Service, USDA).

The Ontario hydrologic unit area is located near the city of Ontario, in Malheur County, in the southeastern corner of Oregon. While the Environmental Protection Agency (EPA) standard for nitrate nitrogen is 10 parts per million (ppm), nitrate levels of 30 to 40 ppm have been reported in the region's groundwater. Groundwater is the primary source of local drinking water and is sometimes a supplemental source for irrigation. The flow pattern in the aquifer is in a northeasterly direction. The city of Ontario is located downstream (northeast) of the agricultural activity believed to be the source of groundwater contamination (fig. 1). Therefore, wells located near Ontario have the most concentrated nitrate

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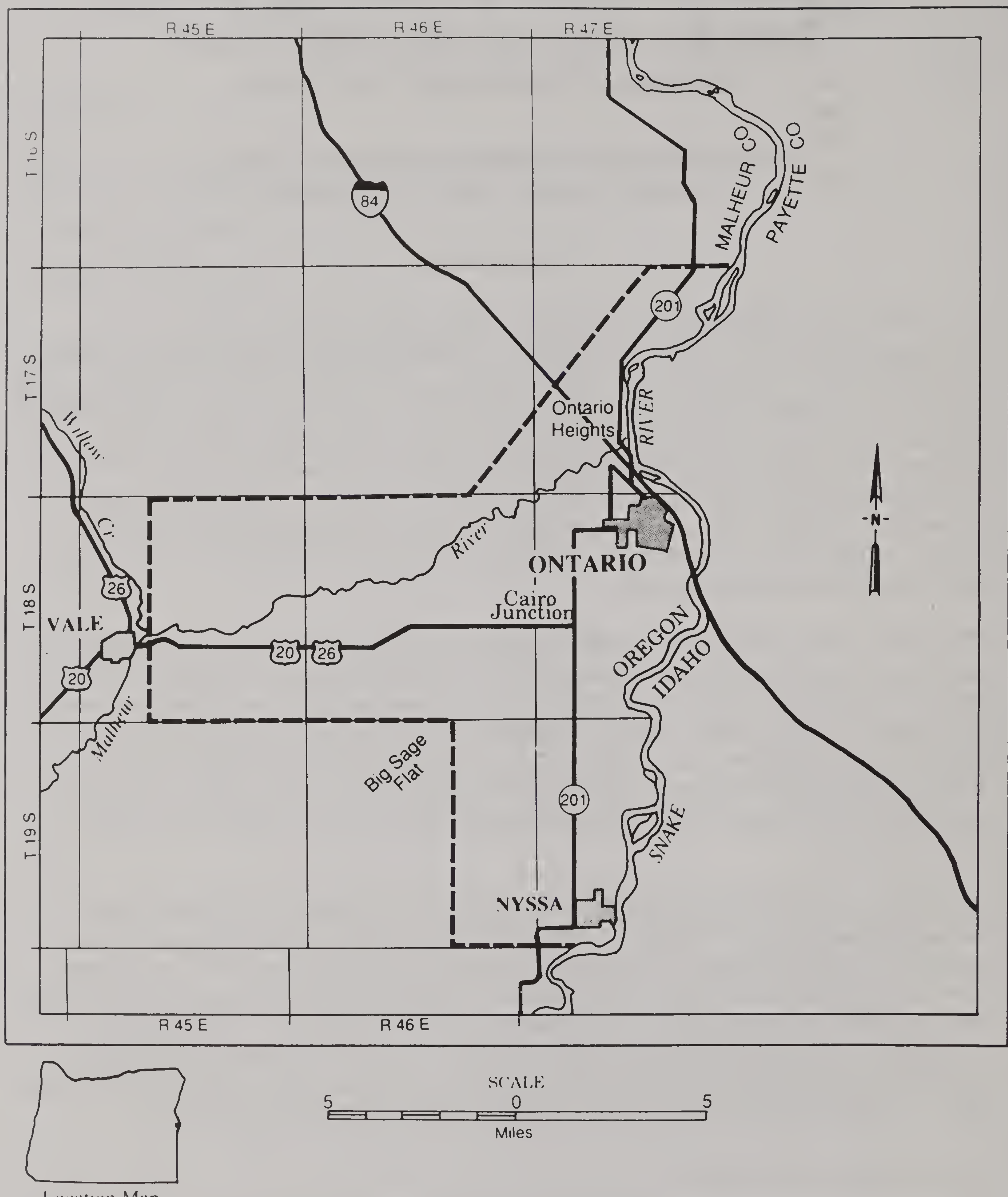

Figure 1. Location map of the Ontario area. The study area is bounded by the dashed line and the Snake River.

contamination problems, with over 70 percent of the wells exceeding 10 ppm (Oregon Department of Environmental Quality).

In this report, we describe the agricultural characteristics and identify a set of best management practices (BMPs) for implementation in the Ontario, Oregon, HUA, and then we provide an economic analysis of BMP adoption. Next, we estimate the impacts on groundwater quality from adoption of these BMPs, and, last, offer our conclusions.

Agricultural Characteristics and the Economic Impacts of Adopting BMPs in the Ontario HUA

Soils in the Ontario HUA are relatively heavy, tending toward the silt loams, and when irrigated, they are very productive. There are approximately 157,000 acres of irrigated cropland in the Ontario HUA. Annual average precipitation ranges from 5 to 16 inches with an average of 10 inches. Irrigation water is delivered through a system of canals by three districts: Vale, Owyhee, and Warm Spring. The base water allocation and its cost vary among the irrigation districts. However, the average base water allocation is 4 acre-feet at an average cost of $25 per acre (Oregon State University Extension Service).

Only 10 percent of irrigated land in the Ontario HUA is under the sprinkler system. The remaining 142,000 acres are surface (furrow) irrigated due to a relatively low price for water and flat topography, well suited to gravity irrigation. Surface irrigation methods range from wild flooding on pastureland to relatively controlled delivery via furrows for row crops. In recent years, however, farmers have invested heavily in both land leveling, to establish uniform grades for better water control, and in concrete lined ditches, to reduce seepage, improve water conveyance efficiency, and reduce irrigation labor (English and Taylor).

Farming practices involving application of irrigation water in excess of crop consumptive-use needs, and widespread use of nutrients containing nitrates and ammonium are generally considered to contribute significantly to the degradation of the groundwater. It is not surprising, therefore, that alternative agricultural practices are being considered in the Ontario HUA, including irrigation management, crop rotation, and nutrient management.

Irrigation Technology

More than 90 percent of irrigated land in the Ontario HUA is furrow irrigated. Alternative furrow irrigation systems being evaluated in the Ontario HUA include pump-back systems, cutback systems, shorter furrows, and automated (set-time) systems for furrow irrigation (English and Taylor). Pump-back systems capture runoff at the end of the furrow and pump it back into the water delivery system so that farmers may apply water at a faster rate, resulting in more uniform stream size. Cutback systems deliver water at a faster rate by applying water at an increased rate, then cutting back the rate when the stream reaches the

end of the furrow. Automated furrow systems, such as automated pump-back, cutback, and short furrow, allow farmers to adjust the rate of water application.

Using a crop simulation model, English and Taylor estimated that the nitrogen application rate needed to maximize yield for potatoes is 397 pounds per acre, higher than normal nitrogen applications for profit maximization in the Ontario HUA region (about 200 to 300 pounds per acre). The estimated nitrogen application rate is then incorporated into an irrigation efficiency model (IEM) to estimate runoff, percolation, and nitrate leaching for furrow irrigation systems. The results, contained in table 1, show that yields from alternative irrigation systems are basically equivalent to those from a standard furrow irrigation system. That is, farmers can reduce nitrate leaching significantly without loss in yield by increasing irrigation efficiency.

Automated pump-back irrigation and cutback irrigation systems reduce water requirements, compared with a standard furrow irrigation system, by 29.3 percent and 16.7 percent, respectively. The alternative furrow systems require more irrigation water than a standard furrow system. For moderately permeable silt loam soils, auto-cutback irrigation systems reduce nitrate leaching and runoff by 76 percent and 29 percent, respectively (table 1). All other furrow irrigation systems reduce nitrate leaching, but increase runoff substantially. Runoff from the soil surface is inversely correlated with infiltration into the soil. While a large volume of water flow creates soil erosion and runoff, which contribute to the degradation of surface water, it reduces percolation. Reduction in percolation from furrow irrigation requires more rapid advance of water flow and a more uniform volume along the full length of the furrow.

Most alternative furrow irrigation systems reduce groundwater pollution by reducing nitrate leaching, while they contribute to surface water pollution by increasing runoff. Only auto-cutback irrigation systems require less irrigation water than standard furrow irrigation systems, as well as reducing runoff to surface waters, and nitrate leaching to groundwater.

Alternative sprinkler systems include wheel line sprinkler and solid-set sprinkler systems (table 2). Sprinkler systems apply water more uniformly than furrow systems and, therefore, result in less percolation. Wheel line sprinkler systems reduce both runoff and nitrate leaching on moderately permeable silt loam soils by 95 percent and 43 percent, respectively. For moderately permeable soil, solid-set sprinkler systems reduce runoff by 100 percent, while reducing nitrate leaching by 84 percent.

In summary, both auto-cutback and solid-set sprinkler systems substantially reduce both runoff and nitrate leaching on silt loam soils. Wheel line sprinkler systems also reduce both runoff and nitrate leaching, but they are not as effective as auto-cutback or solid-set sprinkler systems.

Even though sprinkler systems reduce percolation, farmers have been slow to adopt them, because irrigation water is relatively inexpensive and the capital cost of a sprinkler system is

high relative to the operating cost of a standard furrow system. Capital cost per acre per year is estimated to be $654 for a solid-set sprinkler system versus $279 for an auto-cutback system, and $218 for a standard furrow system (table 3). However, labor costs associated with a solid-set sprinkler system are reduced to $4 per acre per year from $16 per acre per year for standard furrow and auto-cutback systems.

Table 4 compares the annual capitalized value of capital and labor costs associated with the different types of irrigation systems assuming that the expected life of an irrigation system is 20 years. Labor and capital costs associated with alternative irrigation systems in table 3 are used to calculate the annual capitalized value of total costs associated with alternative irrigation systems.

Since yields associated with alternative irrigation systems in tables 1 and 2 are identical to those with the less expensive standard furrow irrigation system, farmers have no incentive to adopt more water efficient, but also more expensive, irrigation systems that reduce runoff and percolation. One incentive to encourage the adoption of a water-conserving irrigation system is public cost-sharing.

Within the Ontario HUA the maximum Federal cost-share is 50 percent of the actual cost for all improved irrigation practices, but cannot exceed $200 per acre and $3,500 per year for up to 5 years for each farmer. The Government share of costs for a 40 acre irrigated field at an 8.5 percent discount rate, therefore, is assumed to be $36.40 per acre per year for both an auto-cutback irrigation system and a solid-set sprinkler system. Auto-cutback irrigation systems reduce nitrate leaching by 76 percent from 36.1 lbs/ac. to 8.8 lbs/ac. on moderately permeable silt loam soils, while solid-set sprinkler systems reduce nitrate leaching by 84 percent from 36.1 lbs/ac. to 5.6 lbs/ac. (tables 1 and 2). Based on these estimated reductions in nitrate leaching, costs to the Government to reduce a pound of nitrate leaching are $1.33/lb/ac. per year for auto-cutback irrigation systems and $1.19/lb/ac. per year for solid-set sprinkler irrigation systems.

Given an assumed life expectancy of 20 years for irrigation systems and with Government cost sharing, the annual capitalized value of total costs at an 8.5 percent discount rate is estimated to be $234 for standard furrow and $258 for auto-cutback irrigation systems, and $621.60 for solid-set sprinkler irrigation systems. At a discount rate of 10 percent, the annual capitalized value of total costs is $258.59 for standard furrow and $285.49 for auto-cutback systems, while it is $691.20 for solid-set irrigation systems.

Average annual costs of labor and capital to farmers adopting solid-set sprinkler irrigation systems at a 5 percent discount rate are approximately $473.50/ac./yr., while they are $181.69/ac./yr. and $200.09/ac./yr. for standard furrow and auto-cutback irrigation systems. These results indicate that the level of cost sharing is not large enough to offset the high capital costs associated with a solid-set sprinkler system. When the reductions in irrigation water and energy use from adoption of improved irrigation technology are considered along

with a relatively low discount rate, the level of cost sharing may be high enough to encourage farmers to adopt an auto-cutback irrigation system.

Crop Rotations

Crop rotations have historically been recommended and accepted practice for nitrogen fixation and control of weeds, insects, and diseases. The importance of crop rotations diminished as relatively inexpensive chemical fertilizers and pesticides became readily available. However, crop rotations have again received attention in connection with their beneficial effects on soil erosion and water quality. Continuous soil cover by crops and residues--a desirable feature of crop rotations--reduces nitrogen losses from leaching and soil erosion.

A rough approximation of the nitrogen balance for the acreages in the Ontario HUA allocated to wheat, potatoes, onions, and sugar beets is presented in table 5. Results show that nitrate leaching can be reduced by crop rotations of wheat-sugar beets, wheat-onions, and wheat-potatoes. These two-crop rotations result in an after-harvest average of 54 lbs/ac./yr. of residual nitrates (Shock and Stieber). Crop rotations of wheat-onions-sugar beets and wheat-onions-potatoes, result in substantially higher nitrates remaining after harvest of 83 lbs/ac./yr. and 88 lbs/ac./yr., respectively.

Net revenues associated with wheat-onions-potatoes and wheat-onions-sugar beets rotations are estimated to be $658/ac./yr. and $633/ac./yr., respectively. These net returns are slightly smaller than those associated with a wheat-onions rotation ($662/ac./yr.), but greater than those associated with wheat-sugar beets ($316/ac./yr.) and wheat-potatoes ($354/ac./yr.).

In summary, three-crop rotations of wheat-onions-sugar beets and wheat-onions-potatoes generate substantially larger profits per acre than two-crop rotations of wheat-sugar beets and wheat-potatoes. But they also increase the nitrates remaining after harvest by 29 ibs/ac./yr. and 34 lbs/ac./yr., respectively, above the average level for two-crop rotations. However, the 1990 Malheur County farm survey reveals that the most common cropping rotations in the Ontario HUA include wheat-onions, wheat-potatoes, wheat-sugar beets, and to a lesser extent, wheat-onions-sugar beets and wheat-onions-potatoes (Ontario Oregon HUA Annual Report, 1991). The primary reasons producers give for having a two-crop rotation are related to disease control, contractual requirements, and widely fluctuating market prices for potatoes, onions, and sugar beets.

Nutrient Management

Nutrient management practices include eliminating fertilizer use in excess of crop needs, timing fertilizer applications, using crop rotations, using animal wastes for fertilizer, using winter cover crops, controlling fertilizer release or transformation, and incorporating surface applications (Frere). Among these, the nutrient management practice most often discussed

for the Ontario HUA is the timing of fertilizer applications, including sidedressing and elimination of fall fertilization.

Efficiency of nitrogen fertilizer use is maximized when fertilizer is applied near the time of maximum vegetative need. The application of nitrogen fertilizers several weeks after the plant has started to grow is commonly called summer sidedressing. Sidedressing reduces the amount of fertilizer used and increases its efficiency, but labor costs increase more than enough to offset the reduction in fertilizer costs (Connor).

Fall fertilization is a common practice in the Ontario HUA. According to the 1990 Malheur County crop survey, 83 percent of onions, 68 percent of sugar beets, and 48 percent of potatoes acreage received more than 50 pounds of nitrogen fertilizer per acre as fall application. For fall fertilization, it is usually recommended that an ammonium-type fertilizer be applied after the soil cools below 50°F, because ammonium is relatively immobile and is converted to nitrate very slowly below 50°F (Frere). Conversion of ammonium to nitrate (nitrification) can be slowed by nitrification inhibitors. Urea is converted into ammonium and then converted to nitrate. Conversion of urea to ammonium can be slowed by sulfur-coating the fertilizer granules (Frere).

Even though fall fertilization is realized to be a problem in terms of the potential for nitrate leaching, no significant effort has been made to investigate the problem. Therefore, it is considered that improved nutrient management is an area in need of additional research.

We have evaluated the economic impacts of adopting best management practices associated with irrigation technologies, crop rotations, and nutrient management. We have confirmed that most farmers in the Ontario HUA have already adopted two-crop rotations of onions-wheat, sugar beets-wheat, and potatoes-wheat, because of contractual requirements and widely fluctuating market prices for potatoes, onions, and sugar beets. It has been shown that auto-cutback irrigation systems not only require less irrigation water than standard furrow irrigation systems, but also reduce surface runoff and nitrate leaching to groundwater. While the magnitude of current cost sharing is not large enough to offset the high capital costs associated with a solid-set sprinkler system, the level of cost sharing is high enough to encourage farmers to adopt auto-cutback irrigation systems. In the following section, therefore, the impact on groundwater quality of adopting an auto-cutback irrigation system will be evaluated.

Impacts on Groundwater Quality of Adopting BMPs in the Ontario HUA

Water stored in the soil, whether from rainfall or irrigation, moves into two geological units: the unsaturated zone (soil scientists use the term "vadose" zone) and the saturated zone. The unsaturated zone extends from the soil surface to the top of the capillary fringe, which separates the unsaturated zone from the saturated zone associated with the water table

aquifer. The vadose zone in the Ontario HUA is characterized by a brown silt layer, and its thickness varies from 10 feet along the Malheur and Snake Rivers to more than 50 feet inland. In general, water movement in the vadose zone is predominantly vertical, and the infiltration rate in the Ontario HUA is estimated to be between 0.6 and 2.0 inches per hour (Peterson and Power).

Figure 2 is a hydrologic map of the Ontario HUA, prepared by the Oregon Department of Water Resources. The vertical topographical height of the water table is called the total potential or total hydraulic head. Lines connecting equal energy or hydraulic head are called equipotential lines. Contour lines in figure 2 represent equipotential lines. The value of the total potential is simply the height of the water table above the datum at the point where the equipotential line intercepts the water table surface.

Groundwater always moves from areas of high potential toward areas of low potential. Furthermore, groundwater moves in a direction perpendicular to the equipotential lines, indicating that the geology is characterized as isotropic. Hydrologic data required for the two- or three-dimensional groundwater and transport models have not been measured in the Ontario HUA. Therefore, it is assumed that the geology is homogeneous (i.e., the hydrologic conductivity does not vary at various locations) and isotropic (i.e., the hydraulic conductivity is the same in all directions at a given point).

Darcy's formula is used to estimate how long it will take nitrates to travel from the Cairo Junction area to the city of Ontario. The Darcy's real velocity, also known as the seepage or pore velocity, is defined by:

$$V_D = - [K/n_{ef}][\Delta H/\Delta X] \qquad (1)$$

where K is a conductivity coefficient, $\Delta H/\Delta X$ is the gradient, and n_{ef} is the effective porosity which is defined as the maximum amount of water that a given volume of geologic material can contain (Cleary, Miller, and Pinder). For the unconfined aquifer, the effective porosity is identical with "specific yield." Specific yield is defined as the volume of water that will drain by gravity in a unit volume of porous medium. Darcy's velocity holds for both saturated and unsaturated flow. In the saturated zone, conductivity coefficient K is a constant at a given location, but within the vadose zone it is a function of moisture content and the type of geology (Cleary, Miller, and Pinder).

No effort has been made to measure parameters associated with water and nitrate movement through the unsaturated zone in the Ontario HUA. Equation 1, therefore, cannot be used to estimate the time it takes for nitrates to travel through the unsaturated zone. However, water infiltration rate is controlled by soil texture, and infiltration rates for various soil textures have been well documented (Peterson and Power). For silt loam soil, the infiltration rate ranges between 0.6 and 2 inches per hour. Since total irrigation hours fluctuate among crops, the weighted average irrigation hour, based on acreage allocated for each crop, is estimated to be 250 hours per year. Distance of nitrate travel is, therefore, estimated to

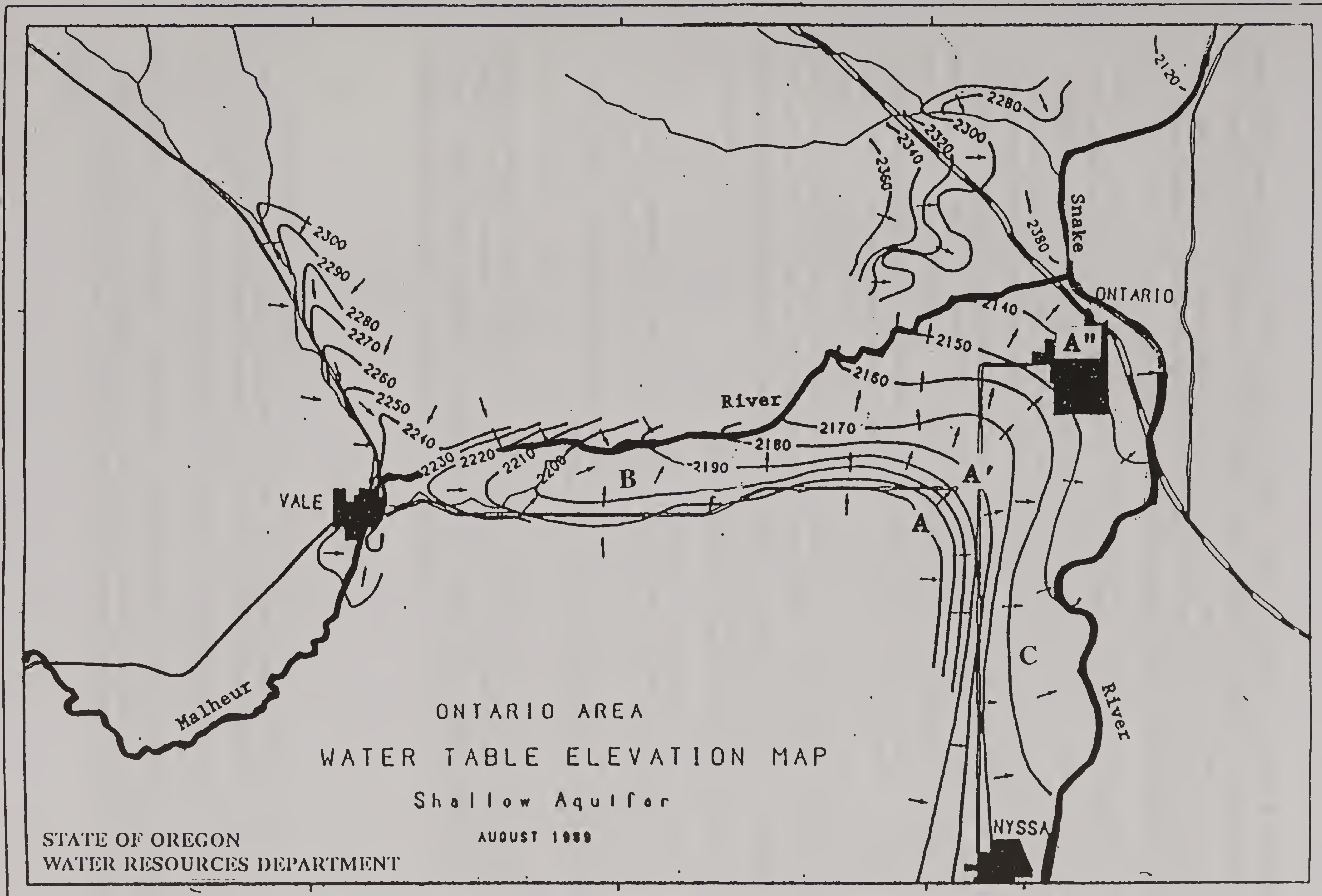

Figure 2. Water table map of the Ontario area.

range from 12.5 feet to 41.7 feet per year, with an average of 27.1 feet per year. Thickness of the unsaturated zone along the Malheur and Snake Rivers is estimated to be 10 feet, while it is 50 feet for inland areas (Gannett). Travel time for nitrates required to reach the groundwater table from the root zone is estimated, on average, to be 4.4 months along the Malheur and Snake Rivers, and 22 months for inland areas.

Following Gannett, conductivity at testing wells in the Ontario HUA is approximately 500 feet per day on average. Specific yield of the sand and gravel aquifer is about 20 percent. The distance between A and A' in figure 2 is approximately 2 miles, while the change in water table level is 41 feet from 2,221 feet to 2,180 feet. The gradient is, therefore, estimated to be .00388 (41/10,560). Similarly, the distance between A' and A" is about 3 miles and the change in water table level is 40 feet, from 2,180 to 2,140 feet. The gradient is approximately .002525 (40/15,840). Using equation 1, the velocity of groundwater flow between A and A' is estimated to be 9.7 feet per day, while it is 6.3 feet per day between A' and A" (table 6). The travel time required for nitrates to move from A to A' is estimated to be approximately 3 years ([2 miles x 5,280 ft/mile]/[9.7ft/day x 365 days/yr] = 2.98 years). Similarly, the travel time from A' to A" is estimated to be nearly 7 years ([3 miles x 5,280 ft/mile]/[6.3 ft/day x 365 days] = 6.89 years). By summing the nitrate travel time through both unsaturated and saturated zones, these results indicate that the total travel time required for a fraction of nitrogen fertilizers applied today on the field in the area A to the discharge area along the Snake River is approximately 12 years.

Flows from points B and C to the Malheur River and Snake River, respectively, are disregarded because they do not affect drinking water. The groundwater flow from point A to the Snake River runs through the region which contains the city of Ontario, where the population depends on groundwater for its drinking water.

The effects on nitrate concentration of a best irrigation management practice can be explained with a mass balance equation. According to mass balance, nitrate movement-in during time Δt less nitrate movement-out in Δt must equal accumulation of nitrates in the aquifer during Δt, and can be represented by the following time differential equation (Cleary, Miller, and Pinder):

$$d(VC_e)/dt = C_iF_i - C_eF_e \tag{2}$$

where C_i and C_e represent nitrate concentration in influent and effluent, respectively, F_i represents vertical recharge and horizontal flow-in, F_e represents withdrawal, horizontal flow-out or discharge of groundwater, and V represents volume of groundwater.

Since groundwater is the primary source of drinking water, and surface waters are used for irrigation in the Ontario HUA, volume of groundwater, V, in equation 2 is assumed to be constant. The solution of the first-order differential equation 2 is then presented as:

$$C_e = C_i[1 - \exp(-F_e/V)t] + C_o \exp(-F_e/V)t \quad (3)$$

where C_o represents the concentration level at year $t=0$. As time approaches infinity, the concentration level reaches a steady-state at $C_e = C_i$. When nitrate leaching to groundwater is reduced by adopting best management practices so that C_i is reduced, the concentration level in effluent C_e is also reduced.

The amount of nitrate inflow from upstream to the point A is not known. Therefore, our estimation begins with the EPA standard of 10 ppm at A" so that C_e in equation 3 equals 10 ppm. By calculating backward in space and time, the concentration level in the influent at point A can be found that would be required to satisfy the standard. An average nitrate concentration level at the testing well (identification number 18S/47E-5Db), located in the Ontario area (A" in figure 2), is 25.0 ppm. Concentration levels of influent at A' and A are 6.8 ppm and 4.4 ppm, respectively (table 7).

Since drinking water is pumped from a shallow aquifer, the concentration level (ppm) at any point is converted into the amount of nitrate leachate per 10 acre-feet per acre at the bottom of the vadose zone. The concentration level of 4.4 ppm at point A in table 7 is equivalent to 24 lbs of nitrate leachate per 10 acre-feet per acre per year at the bottom of the vadose zone, which is larger than the nitrate leachate of 8.79 lbs/ac., with auto-cutback irrigation systems (table 1). This result indicates that the Federal drinking water standard of 10 ppm for nitrates can be obtained by adopting improved auto-cutback irrigation systems.

When we repeat the backward calculation for the State of Oregon target of 7 ppm, the results indicate that such a drinking water standard cannot be obtained by simply adopting an improved irrigation technology. Therefore, the backward flow calculation is made for the drinking water standard of 8 ppm (table 7). The conversion of 1.43 ppm to dry weight results in 7.8 lbs of nitrate inflow per 10 acre-feet per acre per year, which is higher than the 5.6 lbs resulting from adoption of solid-set sprinkler systems, but less than the 8.9 lbs resulting from adopting auto-cutback irrigation systems.

Conclusions

The economic impacts of adopting best management practices are evaluated based upon secondary information and data that are representative of the Ontario HUA. BMPs considered to control groundwater contamination are alternative irrigation technologies, crop rotations, and nutrient management. The 1990 crop survey in Malheur County reveals that most farmers have already adopted two-crop rotations of wheat-onions, wheat-potatoes, and wheat-sugar beets, in response to contractual requirements and widely fluctuating crop prices for onions, potatoes, and sugar beets. Although sidedressing reduces fertilizer use, a previous study indicates that reduced fertilizer cost does not offset the added labor cost (Connor).

Results indicate that both solid-set sprinkler systems and automatic cutback furrow irrigation systems reduce runoff to surface waters and nitrate leaching to groundwater. However, the level of current cost sharing is not sufficient to offset the high capital costs associated with a solid-set sprinkler system, whereas the level of cost sharing is high enough to encourage farmers to adopt the auto-cutback irrigation system.

Results indicate that the Federal drinking water standard of 10 ppm may be accomplished in 12 years by adopting either auto-cutback irrigation systems or solid-set sprinkler systems. However, the Oregon drinking water standard of 7 ppm may not be realized by simply adopting improved irrigation technologies; it will likely also require improved nutrient management. Even a drinking water standard of 8 ppm can hardly be achieved by adopting auto-cutback irrigation systems, but it may be attainable by adopting solid-set sprinkler systems.

Potatoes and onions, which have shallow root systems, generate the highest expected net returns in the Ontario HUA (Connor). For onions, it is necessary to supply water below the crop canopy, using furrow irrigation. Therefore, even though the most effective irrigation technology for reducing nitrate leaching in the silt loam soils appears to be a solid-set sprinkler system, it is very unlikely the adoption rate of solid-set sprinkler systems will increase substantially beyond the current level of less than 10 percent of irrigated land.

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Table 1--Alternative furrow irrigation systems tested on moderately permeable silt loam soils

Irrigation system	Field length	Set time	Adv. time	Dischar.	Yield	Depth appl.	Runoff	Perco-lation	NO_3 leach.
	m	hrs	hrs	l/s	t/ac.	mm	mm	mm	lbs/ac.
Standard	360	24	9.80	.25	30.33	59.22	12.74	21.50	36.13
Pumpback (PB)	360	16	3.60	.42	30.47	76.00	31.84	5.59	19.54
Cutback (CB)	360	16	2.30	.60	30.55	53.83	15.61	8.47	28.20
Short furrows	180	16	1.67	.22	30.67	79.92	37.92	4.65	9.58
Auto-PB	360	8	2.60	.53	30.60	60.00	24.30	1.36	6.80
Auto-CB	360	8	2.30	.60	30.39	40.95	9.09	2.02	8.79
Auto-Short	180	7	.75	.50	30.61	55.90	23.90	1.37	6.84

Source: English and Taylor

Table 2--Alternative sprinkler irrigation systems tested on moderately permeable silt loam soils

Irrigation system	Freq.	Spacing	Appl. rate	Set time	Yield	Depth appl.	Runoff	Perco-lation	NO_3 leach.
	Days	Feet	in/hr.	hrs.	t/ac.	mm	mm	mm	lbs/ac.
Wheel line	8	40 x 60	.24	10.0	30.28	38.77	.69	5.96	20.64
Solid-set	1	30 x 30	.10	3.0	30.31	48.35	.00	.97	5.64

Source: English and Taylor.

Table 3--Annual capitalized value of capital and labor costs associated with alternative irrigation systems: 1990 dollars at an 8.5 percent discount rate

Irrigation system	Labor costs	Capital cost
	$/ac./ yr.	$/ac./ yr.
Standard furrow	15.99	218.01
Auto-cutback	15.99	278.60
Solid-set	4.00	654.02

Source: English and Taylor.

Table 4--Comparison of annual capitalized value of capital and labor costs associated with alternative irrigation systems: 1990 prices

	Interest rate							
	5%				10%			
Irrigation system	Labor cost	Capital cost	Total cost	With cost share	Labor cost	Capital cost	Total cost	With cost share
	$/ac./yr.							
Standard furrow	15.99	165.70	181.69	181.69	15.99	242.60	258.59	258.59
Auto-cutback	15.99	211.80	227.79	200.09	15.99	310.00	325.99	285.49
Solid-set sprinkler	4.00	497.20	501.20	473.50	4.00	727.70	731.70	691.20

Table 5--Estimated nitrogen balance at the Ontario HUA

Crop	Avg. N appl.	Total plant uptake	N in harvested portion	N in crop residual	N carry-over	Net N remaining aft. harvest
	lbs/ac.					
Wheat	136	181	142	39	-45	-6
Sugar beets	205	239	136	103	-34	69
Onions	284	130	99	31	154	185
Potatoes	215	162	130	32	53	85

Source: Shock and Stieber

Table 6--Geohydrologic data for the Ontario HUA

Item	Point between A and A′	Point between A′ and A″
Initial contamination level, C_o at A″	-----	25 ppm with wide variation
Distance	2 miles	3 miles
Effective porosity (n_{ef})	20%	20%
Conductivity, K	500 ft. / day	500 ft. / day
Velocity	9.7 ft. / day	6.3 ft. / day
Travel time	3 years	6.9 years

Table 7--Nitrate concentration level required under the EPA standard for the Ontario HUA

Location	Scenario I[1]	Scenario II[1]
Point A′	6.81 ppm	4.38 ppm
Point A	4.41 ppm	1.43 ppm
Nitrate leachate	5.64 lbs/ac. with solid-set sprinkler system 8.79 lbs/ac. with auto-cutback irrigation system	

[1] Scenarios I and II require that nitrate concentration level at point A″ is 10 ppm and 8 ppm, respectively.

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